Responses of Source and Sink Manipulations on Yield of Selected Rice (Oryza Sativa L.) Varieties

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***Abstract*—Five Malaysian rice varieties (MR263, MR219, MR167, MR84, and Pulut Siding), were grown in polybag culture under glasshouse condition and were subjected to source and sink manipulations (50% flag leaf cutting, 25 and 50% spikelet removal, and control) for the grain yield and yield components response. Manipulation on grains number has caused the lower grain yield of all rice varieties. In response to the spikelet removal, the grain size of two varieties (MR167 and Pulut Siding), and the filled grain in the basal spikelets of three varieties (MR263, MR167, and MR84) increased about 2 - 6% and 7 - 13%, respectively. In response to the flag leaf cutting, the grain size of three varieties (MR263, MR84, and Pulut Siding), and the filled grain in the apical spikelets of four varieties (MR263, MR219, MR84, and Pulut Siding) reduced about 2 - 6% and 2 - 8%, respectively. Less than 80% of filled grain suggested that the grain yield of MR263, MR219, MR167, and MR84 were limited by the source activity, more than sink capacity. The significant increment of grain size and more than 80% of filled grain suggested that the grain yield of Pulut Siding was limited by both the source activity and sink capacity.**

***Index Terms*—grain yield, yield components, source and sink manipulations, source activity, sink capacity.**

I. Introduction

Grain yield in rice can be defined as the product of filling efficiency [1]. Grain filling is the most critical and important developmental stage in rice plant which contributes to higher crop yield in cereals. It is a continuous, asynchronous and integrative process and will go through a series of changes, which is initially slow, before it enters a linear phase with the fast growth rate and then slows down before the grain is fully matures [2]. However, the unbalance allocation pattern of photo-assimilate among spikelets within a panicle is a major problem and still unsolved in rice production. Spikelets formed on the individual panicle close to the culm were termed as basal spikelets and produced a partially filled poor quality grain in contrast to the apical spikelets (spikelets located further from the culm) [3]. The grain weight and filling rate of basal spikelets can be as low as 21% compared to the apical spikelets [4], [5].

Previous studies showed that the grain filling rate is characterized by the source activity relative to sink size, the capability of carbohydrate accumulation and also the translocation of assimilates from source tissues to spikelets [6], [7]. Starting from florets as the primary photosynthate sink, and the top three leaves on a stem, particularly the flag leaf, are the primary source. Study made by [8] observed that there was a negative correlation between yield and percentage sterility of rice genotype. Reducing the spikelet sterility or increase spikelet fertility would be the choice to increase rice yield. Selection of varieties with large sink size (by increasing the number of grains per panicle) would be best in producing high grain yield [9], [10]. A large sink size, as well as an efficient transport of photo-assimilate from leaves and stems to developing spikelet is required in producing high yield and high harvest index of the entire plant [9]. Moreover, the capacity to transport photo-assimilate from source to sink (e.g. the number of large vascular bundle) could also be the base photo-assimilate limitation of grain filling. Varieties with compact panicle types, characterized by short panicle with high grain density within panicle, had become available and reported to have a yield potential of 8 to 20% more than other conventional rice varieties [5], [11]. However, more previous studies revealed that the compact panicle varieties produced relatively lower in filled grain percentage and grain weight [12].

Manipulation of source-sink ratios would be the suitable method to study the grain filling process in rice plant [13], [14]. The artificial reduction in grain number per inflorescence is suggested as the technique to increase the photo-assimilate supply for developing grains [15], [16]. While, removal the flag leaf or a portion of it was expected to reduce the amount of photo-assimilate available to developing kernels [17]. Artificial

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manipulations of the sink and source ratio and evaluation of the variation in photo-assimilate partitioning in different rice varieties would be useful in determining the existence of genotypic differences in the response of availability of photo-assimilate.

II. Methodology

A. Rice Varieties, Experimental Site, Design, and Soil Properties

Five released Malaysian rice varieties (MR263, MR219, MR167, MR84, and Pulut Siding) were grown in this study. All rice varieties were grown and maintained until hard dough stage. The experiment was conducted under a glasshouse condition at Universiti Putra Malaysia (UPM) using polybags (30cm x 15cm) filled with 5 to 6kg (3/4 of the polybag size) of rice soil (0.04m^2 surface dimension). All the polybags containing the soil were submerged in the polyethylene tanks (72cm x 50cm x 30cm) for about two weeks before planting (four polybags per polyethylene tanks). The distance between plants was 20cm (3 plants per polybag). The soil used was obtained from Tanjung Karang, a major rice growing area located in Kuala Selangor, Peninsular Malaysia. The soil was loamy in texture (19.1% fine sand, 52.5% silt, 15% clay) and acidic in reaction (pH 4.7) with EC 488 µS/cm; soil nutrient status was 0.56% total N, and 31.4 ppm available P.

B. Treatments

At heading stage, tillers were subjected to the following treatment; (i) *Source strength:* 50% flag leaf cutting (half portion of flag leaf at each tiller was cut), (ii) *Sink strength:* 25% spikelet removal (every fourth floret was removed starting from the topmost of each rachis), and 50% spikelet removal (every second floret was removed starting from the topmost of each rachis), and (iii) Control. All rice varieties were grown and maintained until hard dough stage.

C. Sample Collection

At hard dough stage when grains begin to lose their green color [18], ten panicles bearing tillers were randomly sampled and cut at the soil surface from each treatment (rice varieties with source-sink manipulations). The grain yield and yield components [grains number, grain size, percentage of filled grain (apical and basal spikelets), and harvest index] were measured. For dry mass determination, whole plant and panicles were dried in the oven at 70^{o}C for 48 hours before weighing. The grain yield and yield components were determined after drying. The grain yield was based on the weight of filled grains per hill, and expressed in grams per hill (g hill^{-1}). Grains number were measured and calculated manually. The grain size (mg grain^{-1}) was derived from 100-grain weight. Prior to weighing of the grains, the fully filled grains were separated from the unfilled grains manually. In this experiment, the panicle was equally divided into (i) apical, and (ii) basal part. Grains formed on the individual panicle close to the culm were termed as basal spikelets and further from the culm as apical spikelets.

The partitioning of dry matter between grain yield and vegetative part is indicated by harvest index. Harvest index was calculated as the ratios of grain dry weight to the total aboveground weight and expressed in percentage (%);

Harvest Index

$$= \frac{\text{Grain dry weight}}{(\text{grain + total aboveground dry weight})} \times 100\%$$

D. Determination of Percentage of Filled Grain during Grain Filling Period

Plants were cut aboveground at 5-day intervals from 10 days after flowering (DAF) up to 30 DAF. The sign of flowering was noted when anthers exserted from the lemma and palea of the spikelet. In this experiment, ten panicles bearing tillers from each treatment (rice varieties and source-sink manipulations) were sampled. The total percentage of filled grains for each of the part of panicle (apical and basal spikelets) was calculated using method as described below;

Percentage of filled grain per panicle

$$= \frac{\text{Number of filled grains}}{[\text{Filled + unfilled grains}]} \times 100\%$$

E. Statistical Analysis

The experiment was arranged in a completely randomized design (CRD), with a split plot arrangement with four replicates. This design was adopted due to the uniformity of the glasshouse conditions such as temperature and solar radiation. Moreover, this design was chosen due the fact that the same type of experimental soil was used, and all polybags received equal amounts of water and the same cultural practices. Treatments consisted of a factorial combination of five rice varieties and four source and sink manipulations. The data were analyzed using ANOVA, and the significant means were separated by least significant difference (LSD) test at $P \leq 0.05$.

III. Results and Discussion

A. Effects of Source and Sink Manipulations on Grain Yield and Yield Components

The effect of rice variety on the grain yield, grains number, grain size, and percentage of filled grain (apical and basal spikelets) was significant at $P \leq 0.01$ (Table I). All the yield components measured [grain yield, grains number, grain size, percentage of filled grain (apical and basal spikelets), and harvest index] were significantly affected by the source-sink manipulations. There was also significant interaction between rice variety x source-sink manipulations (V x T) for all yield components measured, with the exception of grains number, grain size, and harvest index.

Results showed that there was a significant difference on the grain yield for the treatment of spikelet removal and control (Table II). Compared to the control, the 50%

flag leaf cutting, 25 and 50% spikelet removal were observed to decrease their grain yield by 6, 25, and 43%, respectively.

Moreover, manipulations on sink capacity (25 and 50% spikelet removal) have contributed to a significant and lower grains number. Reversal trend was observed in case of grain size. The 25 and 50% spikelet removal recorded a significant higher individual grain size, which it increased about 4% if compared to the control. On the other hand, the 50% flag leaf cutting recorded the lowest individual grain size, which it decreased about 3% if compared to the control.

The 25% spikelet removal and 50% flag leaf cutting shows a significant lower percentage of filled grain in the apical spikelets if compared to the control (Table II). The declining following the above order were 2 and 4%, respectively. The same trend occurred in the basal spikelets, when the 25% spikelet removal and 50% flag leaf cutting produced lower percentage of filled grain, with the declining of 2 and 10%, respectively. Reversal trend with 4% increment of filled grain occurred in the basal spikelets of the 50% spikelet removal. Meanwhile, there was no significant effect in the apical spikelets between the control and 50% spikelet removal. Only The treatment of 50% flag leaf cutting was observed to have a significant lower harvest index, which it decreased about 4% compared to the control.

TABLE I. MEAN SQUARE ERROR FROM ANALYSIS OF VARIANCE OF GRAIN YIELD AND YIELD COMPONENTS OF FIVE RICE VARIETIES AND FOUR TYPES OF SOURCE-SINK MANIPULATIONS

Source of variation	df	Grain yield (g hill^{-1})	Grains number (grains panicle^{-1})	Grain size (mg grain^{-1})	Filled grain (% panicle^{-1}) Apical	Filled grain (% panicle^{-1}) Basal	Harvest Index (%)
Variety (V)	4	38.64**	1038.80**	9.41**	323.28**	377.35**	68.09^{ns}
Rep (variety)	15	3.57*	10.06^{ns}	15.37**	23.30**	150.57**	142.12**
Source-sink manipulation (T)	3	166.59**	20157.06**	11.14**	54.55**	308.52**	67.46*
V x T	12	2.35**	51.06^{ns}	0.62^{ns}	27.84**	131.84**	5.87^{ns}

Note: **, significant at $P \leq 0.01$; *, significant at $P \leq 0.05$; ns, non significant

TABLE II. EFFECT OF SOURCE-SINK MANIPULATIONS ON YIELD AND YIELD COMPONENTS OF FIVE RICE VARIETIES

Source-sink manipulation	Grain yield (g hill^{-1})	Grains number (grains panicle^{-1})	Grain size (mg grain^{-1})	Filled grain (% panicle^{-1}) Apical	Filled grain (% panicle^{-1}) Basal	Harvest Index (%)
50% flag leaf cutting	13.8^{b}	138.8^{a}	20.5^{c}	83.4^{c}	53.5^{c}	32.7^{b}
25% spikelet removal	11.0^{c}	98.6^{b}	22.0^{a}	85.3^{b}	58.3^{b}	37.0^{a}
50% spikelet removal	8.4^{d}	72.0^{c}	22.1^{a}	86.7^{a}	62.9^{a}	36.0^{ab}
Control	14.8^{a}	135.0^{a}	21.2^{b}	87.1^{a}	59.9^{ab}	35.1^{ab}

Note:Different superscript (a, b, c, d) in the same column indicate significant difference among treatments. Values are expressed as mean.

Table III shows the effects of source-sink manipulations on yield and yield components among different rice varieties grown in this study. The sink manipulations (25 and 50% spikelet removal) has reduced the grain yield in all rice varieties, with MR219 showed the highest declining percentage of grain yield for both sink manipulations by 40 and 51%, respectively. Similar trend occurred in the 50% flag leaf cutting of MR84 variety. The grain yield decreased about 13% and has contributed to a significantly lower grain yield of MR84.

All rice varieties significantly decreased their grains number when 25 and 50% spikelet was removed from each panicle (Table III). MR263 and MR167 was observed to produce the highest and lowest grains number as compared to the other varieties with about 150 and 119 grains panicle^{-1}, respectively. All rice varieties shows an increasing trend of individual grain size when 25 and 50% spikelet was removed from each panicle (Table III). However, only MR167 and Pulut Siding produced a significantly higher grain size with the increment of 2 - 6% if compared to the control. Disturbing the source strength (50% flag leaf cutting) had also reduced the grain size of all rice varieties grown in this study. Four rice varieties (MR263, MR167, MR84, and Pulut Siding) produced a significantly lower grain size which has declined about 2 - 6% if compared to the control. Based on the present results, there was a wide difference between the percentage of filled grain in the apical and basal spikelets. However, a different proportion of spikelet removal and flag leaf cutting has caused a variation effects on the percentage of filled grain in both the apical and basal spikelets and among different rice varieties. The 50% flag leaf cutting on the apical spikelets has caused four rice varieties (MR263, MR219, MR84, and Pulut Siding) to decline about 2 - 8% and produced lower percentage of filled grain. The same trend showed in the basal spikelets of three rice varieties (MR219, MR84, and Pulut Siding). The declining following the above order were 26, 18, and 14%, respectively. However, a reversal trend showed in the apical and basal spikelets of MR167, which the 50% flag leaf cutting has caused 9% increment of its filled grain.

The 25% spikelet removal has caused the decline of filled grain in the apical spikelets by 3 - 4% in three rice varieties (MR263, MR219, and MR84) to produce lower percentage of filled grain. The same trend occurred in the basal spikelets of MR167 and MR219, which has declined about 5 and 17% of the filled grain compared to the control, respectively. In contrast, reversal trend showed in the apical spikelets of MR167, when the filled grain increased by 2%. The 25% spikelet removal on the basal spikelets of MR84 also showed the same trend, which the filled grain increased by 9% compared to the control.

Moreover, the 50% spikelet removal has caused a different significant effect on each rice variety. Among those five rice varieties, the 50% spikelet removal has caused MR167 to increase about 9 and 13% to produce significantly higher filled grain in the apical and basal spikelets, respectively. Moreover, the 50% spikelet removal has also caused two rice varieties (MR219 and MR84) to decrease about 4 - 6% of their filled grain in the apical spikelets. In contrast, the 50% spikelet removal has increased the filled grain in the basal spikelets of MR84 and MR167 by 9 and 13%, respectively. MR219 showed a reversal trend and has decreased its filled grain in the basal spikelets by 15%.

TABLE III. EFFECTS OF SOURCE-SINK MANIPULATIONS ON YIELD AND YIELD COMPONENTS AMONG DIFFERENT RICE VARIETIES.

Variety	Source-sink manipulations	Grain yield (g hill^{-1})	Grains number (grains panicle^{-1})	Grain size (mg grain^{-1})	Filled grain (% panicle^{-1}) Apical	Basal	Harvest Index (%)
MR263	50% flag leaf cutting	15.0^{a}	148^{a}	20.8^{b}	79.5^{b}	54.3^{b}	32.7^{a}
	25% spikelet removal	12.1^{b}	110^{b}	22.3^{a}	77.4^{c}	59.0^{a}	39.1^{a}
	50% spikelet removal	8.9^{c}	78^{c}	22.6^{a}	79.9^{ab}	58.8^{a}	37.0^{a}
	Control	16.4^{a}	150^{a}	22.2^{a}	80.8^{a}	54.2^{b}	36.4^{a}
MR219	50% flag leaf cutting	13.2^{a}	138^{a}	20.1^{a}	83.4^{c}	50.9^{c}	32.1^{a}
	25% spikelet removal	8.9^{b}	90^{b}	20.7^{a}	87.0^{b}	57.0^{c}	38.5^{a}
	50% spikelet removal	7.1^{c}	68^{c}	20.8^{a}	84.7^{c}	58.7^{b}	36.8^{a}
	Control	14.7^{a}	132^{a}	20.2^{a}	89.3^{a}	68.8^{a}	35.2^{a}
MR167	50% flag leaf cutting	13.8^{a}	125^{a}	19.4^{b}	89.6^{b}	58.8^{a}	36.7^{a}
	25% spikelet removal	10.2^{b}	95^{b}	21.6^{a}	89.3^{b}	50.3^{b}	39.1^{a}
	50% spikelet removal	8.1^{c}	68^{c}	21.1^{a}	96.7^{a}	61.1^{a}	36.5^{a}
	Control	12.8^{a}	119^{a}	19.8^{b}	88.2^{c}	53.2^{b}	38.6^{a}
MR84	50% flag leaf cutting	11.3^{b}	130^{a}	18.8^{b}	80.4^{c}	46.0^{c}	32.1^{a}
	25% spikelet removal	10.3^{b}	98^{b}	20.4^{a}	84.0^{b}	61.9^{a}	35.2^{a}
	50% spikelet removal	7.3^{c}	68^{c}	20.7^{a}	81.7^{c}	61.0^{a}	34.7^{a}
	Control	13.1^{a}	125^{a}	20.0^{a}	87.3^{a}	56.4^{b}	33.4^{a}
Pulut Siding	50% flag leaf cutting	15.6^{a}	148^{a}	22.4^{c}	84.3^{b}	57.7^{b}	29.9^{a}
	25% spikelet removal	13.4^{b}	103^{b}	23.2^{a}	89.1^{a}	69.3^{ab}	33.1^{a}
	50% spikelet removal	10.6^{c}	78^{c}	23.2^{a}	90.7^{a}	75.0^{a}	35.0^{a}
	Control	17.1^{a}	143^{a}	22.8^{b}	90.1^{a}	67.1^{ab}	31.9^{a}

Note:Different superscript (a, b, c, d) in the same column indicate significant difference among treatments. Values are expressed as mean.

Based on the results in previous studies, there was a positive and significant correlation between the number of grains per plant and grain yield [8], [19]. The manipulation on grains number which had effects on grain yield might be the main reason causing the lower grain yield in the 25 and 50% spikelet removal in all rice varieties. On the other hand, defoliation (flag leaf cutting) had a significant negative effect on grain yield and grain size, as well as producing higher unfilled grains per panicle. This results indicated that grain sterility in rice mainly due to unavailable photo-assimilates supply to grains. Previous studies reported that the flag leaf cutting might lead to the enhancement of the photosynthetic activity of other leaves and green parts of plant and remobilization of stored carbohydrates [20], [21]. However, the gain from the remobilization of assimilate could not compensate the loss of biomass production, leading to the reduction in grain yield and grain size. This explained the trend of lower grain yield, grain size, and filled grain when 50% portion of flag leaf was cut during the present study.

The grain size was larger in the spikelet removal treatments might be due to increase supply of photo-assimilates from source to limited sink (few number of spikelets). The variations in grain development and quality within a panicle was attributed to the difference in distributing pattern of photo-assimilate among grains in a panicle, which influence by the difference in sink capacity among grains [22], [23]. Moreover, [24] suggested that the grains with increased grain weight in responses to more supply of assimilates, were under source limited. This indicates that sink manipulation treatment showed that Pulut Siding is source limited and which suggested it can produce heavier grains if it had more assimilate supplied.

B. Pattern of Grain Filling among Rice Varieties during Grain Filling Period

Conversely, the percentage of filled grain increased with passage of time from 10 days after flowering (DAF) to 30 DAF, and the apical spikelets contained higher percentage of filled grain compared to the basal spikelets in all rice varieties (Fig. 1). In this study, Pulut Siding was observed to have the highest percentage of filled grain starting from 10 to 30 DAF, in both the apical and basal spikelets compared to the other varieties (Fig. 1).

Different trend showed in MR263. Even though MR263 produced higher grain yield in this study, the percentage of filled grain was the lowest compared to the other varieties especially in the basal spikelets during early reproductive stages (10 to 20 DAF). Meanwhile, MR167 which produced the lower grain yield in this study was observed to have quite higher percentage of filled grain in both the apical and basal spikelets compared to the other varieties.

The 25 and 50% spikelet removal has caused a higher percentage of filled grain in the basal spikelets of all rice varieties (MR263, MR219, MR84, MR167, and Pulut Siding) from 10 to 30 DAF (Fig. 1). In contrast, the 50% flag leaf cutting has caused a reversal trend especially on two rice varieties (MR219 and Pulut Siding) which showed the lowest percentage of filled grain from 10 to 30 DAF. A different trend showed in MR167 during 30 DAF, when the 50% flag leaf cutting recorded higher percentage of filled grain in the basal spikelets, compared to the 25% spikelet removal and control. Moreover, different trend of filled grain showed among different varieties in the apical spikelets (Fig. 1). The 25 and 50% spikelet removal, and 50% flag leaf cutting have caused two rice varieties (MR167 and MR219) to produce lower percentage of filled grain. A reversal trend showed in MR263, when the spikelet removal and flag leaf cutting has caused a higher percentage of filled grain compared to the control in the apical spikelets, especially during 10 to 25 DAF.

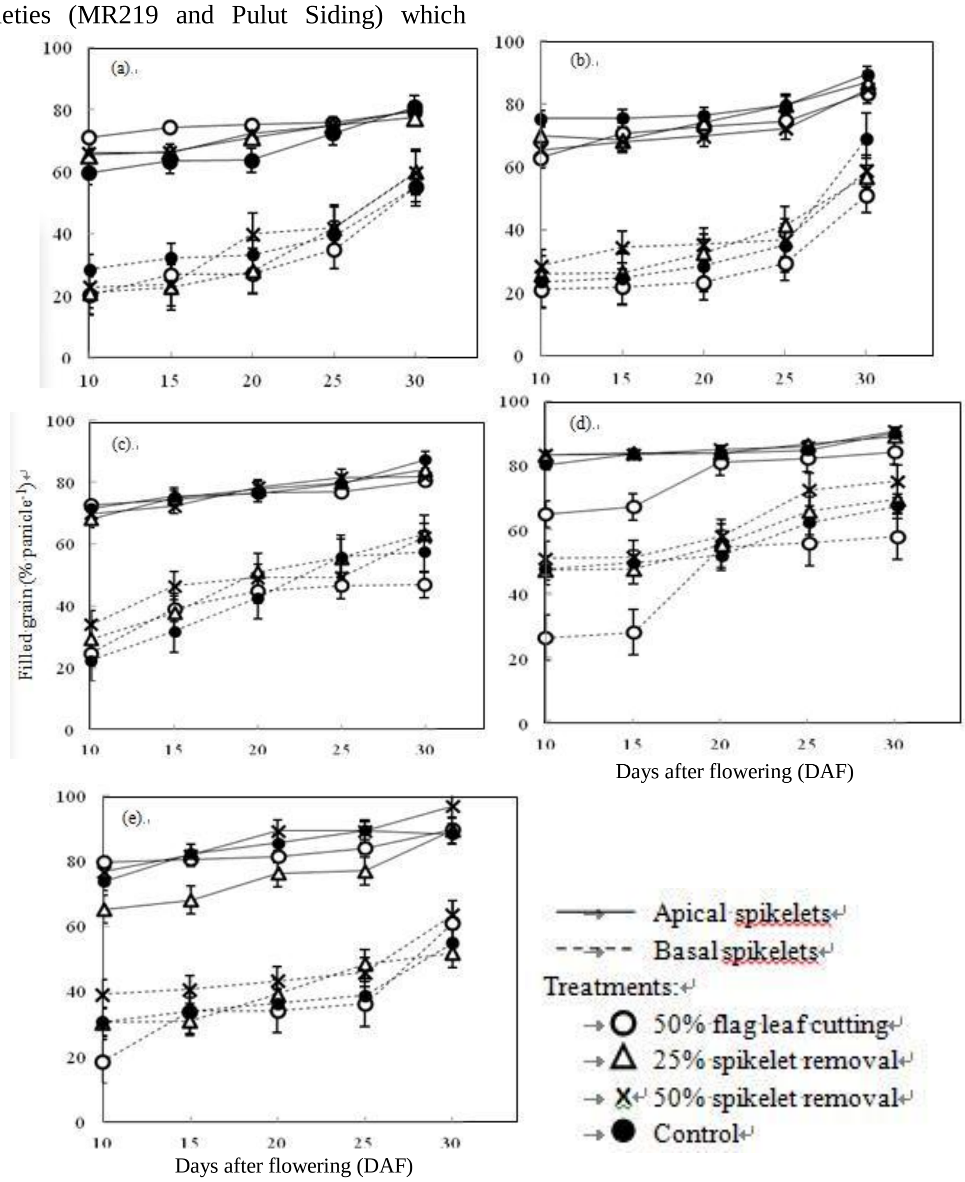

Figure 1. Percentage of filled grain in developing apical and basal spikelets during grain fillingin different rice varieties and source-sink manipulations from 10 to 30 DAF. Note: (a) MR263, (b) MR219, (c) MR84, (d) Pulut Siding, and (e) MR167.

Comparing percentage of filled grain between apical and basal part of panicle results showed that percentage of filled grain was greater in the apical than the basal part. The trend of decreasing unfilled grain setting probability with decreasing nodal position within panicle is consistence with the results of other studies. [25] studied assimilate translocation pattern within panicle in rice and reported that the basal and apical spikelets accounted 40 and 60% of the translocated carbon, respectively. These data indicates that most of the carbohydrate produced by leaves is used in filling the spikelets that occur at apical position of the panicle. These data further suggest that there might be an inadequate supply of assimilates to fill the proximal spikelets. Spikelets which formed early in the reproductive phase (apical spikelets) had longer duration of growth and development, and were longer than spikelets which formed later (basal spikelets) [26]. The competition for assimilate might be actively happened during this time between the apical and basal spikelets, as the basal spikelets only starts flowering 5 to 6 days after the apical ones [3]. Moreover, the late developed basal spikelets, usually have their peak period of growth during the senescence stage. Senescence stage which was programmed genetically causing the flag leaf and the other photo-assimilatory tissues of the plant to become source-limited for assimilate, causing poor assimilate partitioned to the basal spikelets. The source limitation could be the cause of the significant decrease of their grain yield.

According to [27], kernel number has to be reduced to an optimum point at which competition among kernels for assimilate no longer exists, thus producing the potential kernel weight.During the present study, reducing the grains number has caused a significant increment of total filled grain of MR263, MR167, MR84, and Pulut Siding. Removal of spikelet did not altered the senescence pattern of the photosynthetic tissues [7], which explained that the rice plant with lower sink capacity might reduce the competition for assimilate among grains. Previous study made by [28], they concluded that the sink capacity could be the limiting factor of yield, if only the matured grain ratio is more than 80 percent. During the present study, the spikelet removal treatment has caused Pulut Siding to obtain more than 80% of total filled grain, which revealed that the yield of this variety was also limited by the sink capacity. In contrast, the spikelet removal and flag leaf cutting treatments have caused the other four rice varieties (MR263, MR219, MR167, and MR84) to obtain less than 80% of filled grain, which revealed that the supply of assimilate might be the limiting factor of the rice yield.

IV. Conlusion

Manipulation on grains number which had strong effects on grain yield might be the main reason causing the lower grain yield in the 25 and 50% spikelet removal in all rice varieties. The 50% flag leaf cutting drastically reduced grain size and percentage of filled grain in both the apical and basal spikelets proved that flag leaf played an important role to be the main source producing the photo-assimilate. Moreover, the results suggested that the grain yield of MR263, MR219, MR167, and MR84 were limited by the source activity, more than sink capacity. In contrast, the grain yield of Pulut Siding would be the only variety limited by both the source activity and sink capacity.

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